Stochastic Effects in Chemically Amplified Resists for Extreme Ultraviolet Lithography

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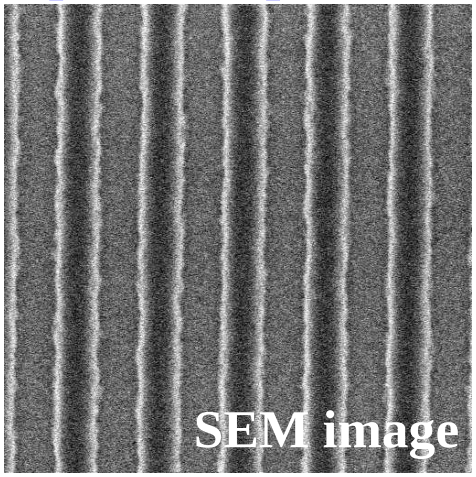
Evaluation of resist materials

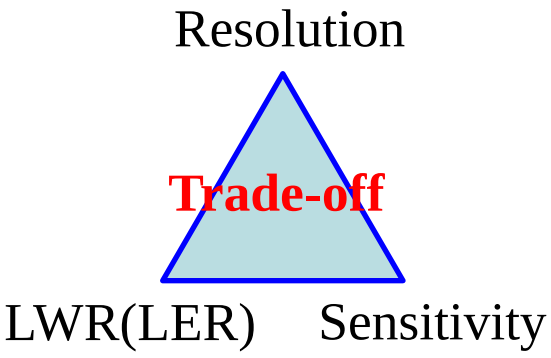
Exposure experiments



Resolution, Sensitivity, LWR(LER)

The performance of resist materials is generally evaluated by comparing the resolution, LER, and sensitivity.

Trade-off relationship



For example, high sensitivity does not necessarily mean high performance.

The evaluation of the potential capability of resist materials is tricky because of the trade-off relationships between these factors.

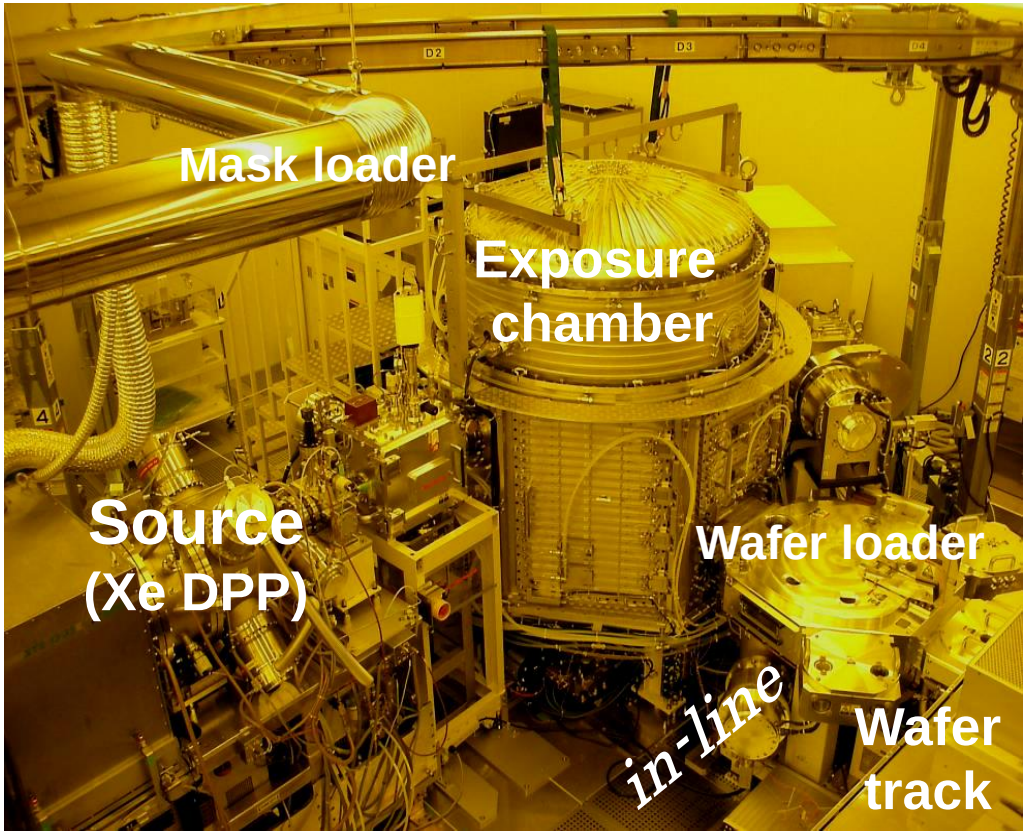
It is essential to the evaluation and development of resist materials to extract information from SEM images as much as possible.

Objective

Establishment of scientific foundation and technology for resist evaluation

The stochastic effect in line-and-space patterns fabricated using SFET was analyzed to clarify the relationship of stochastic effect to LER and resist pattern defects.

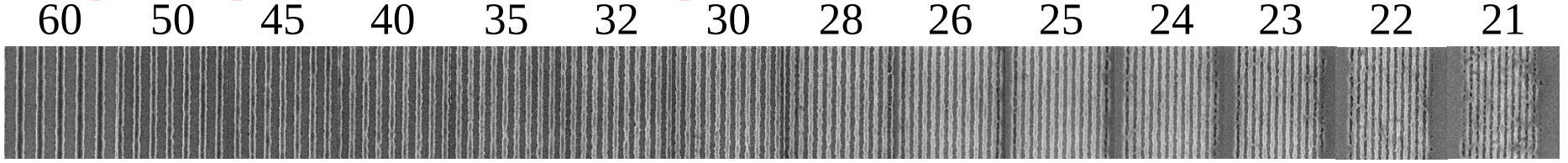
Small Field Exposure Tool : SFET



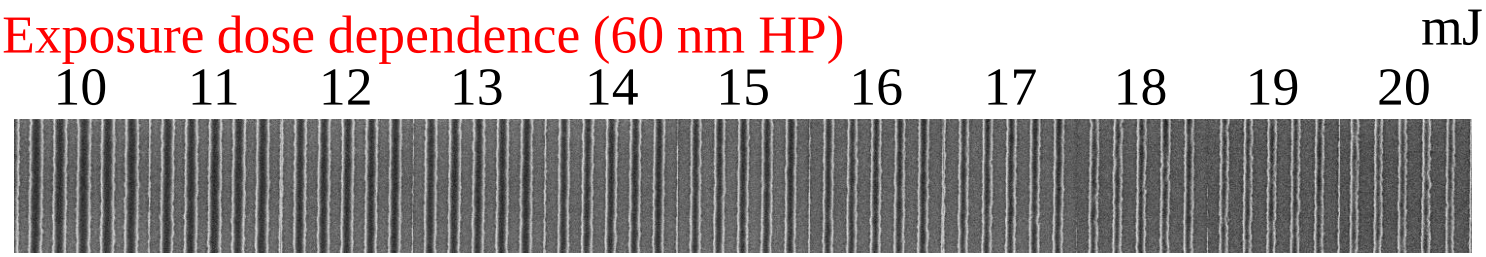
Items	Target Specifications
NA	0.3
Illumination mode	Annular(0.3/0.7), x-slit
Field size	0.2 x 0.6 mm
Magnification	1/5
Wavefront error	＜0.9 nm rms
Flare	＜7%（MSFR）
Source power	0.5W @IF
Wafer size	300 mm

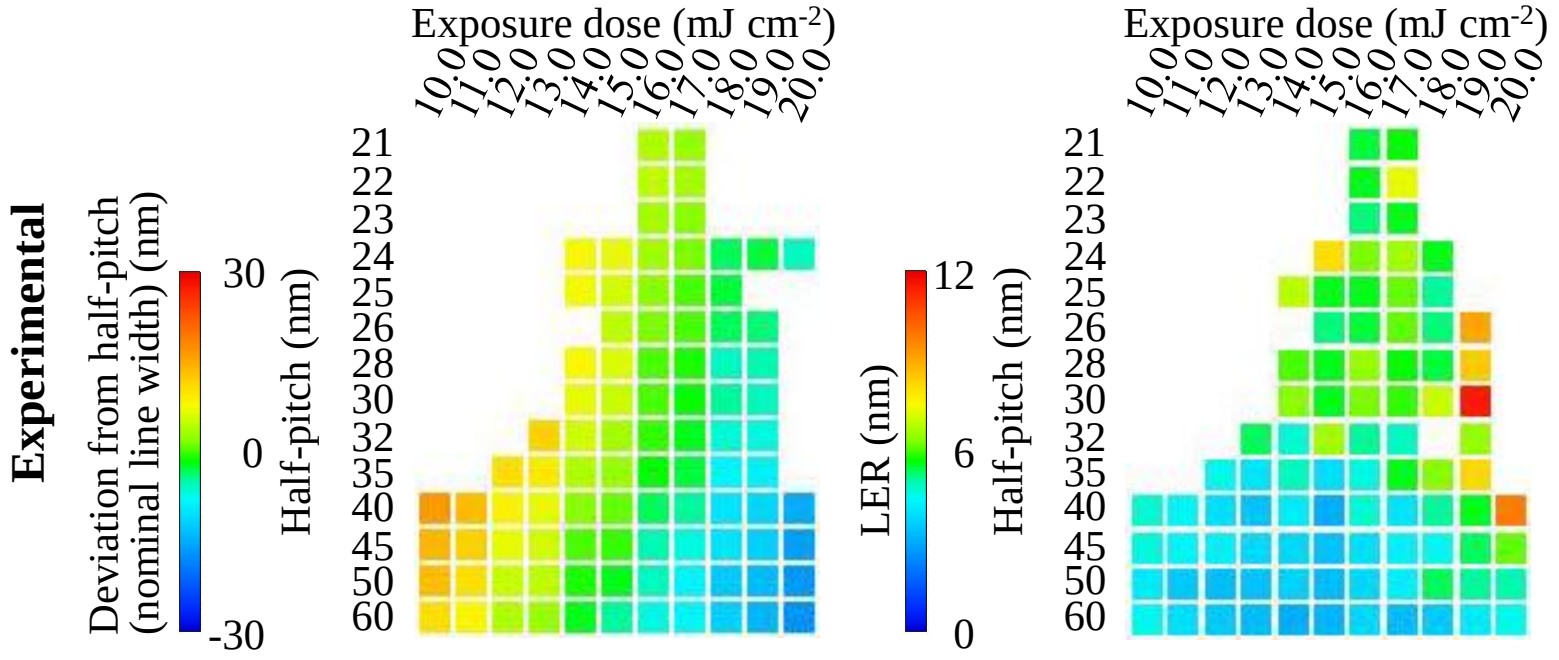
Dose-pitch matrices of EIDEC standard resist

Half-pitch dependence (16 mJ cm^{-2} exposure dose)



Exposure dose dependence (60 nm HP)

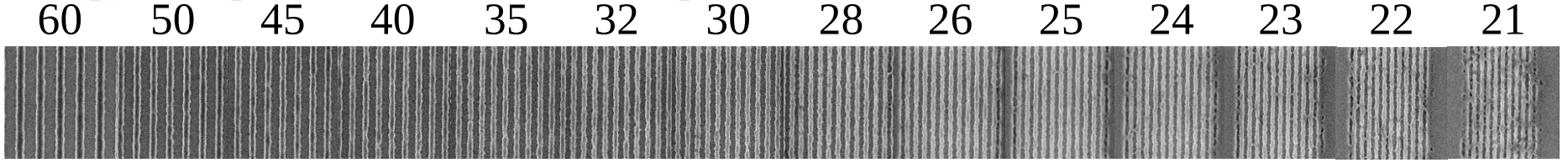




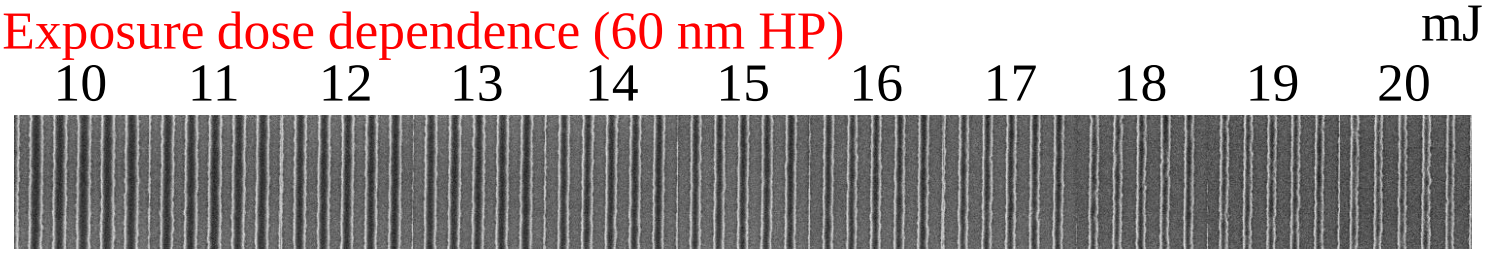
(a) Line width **(b) LER**

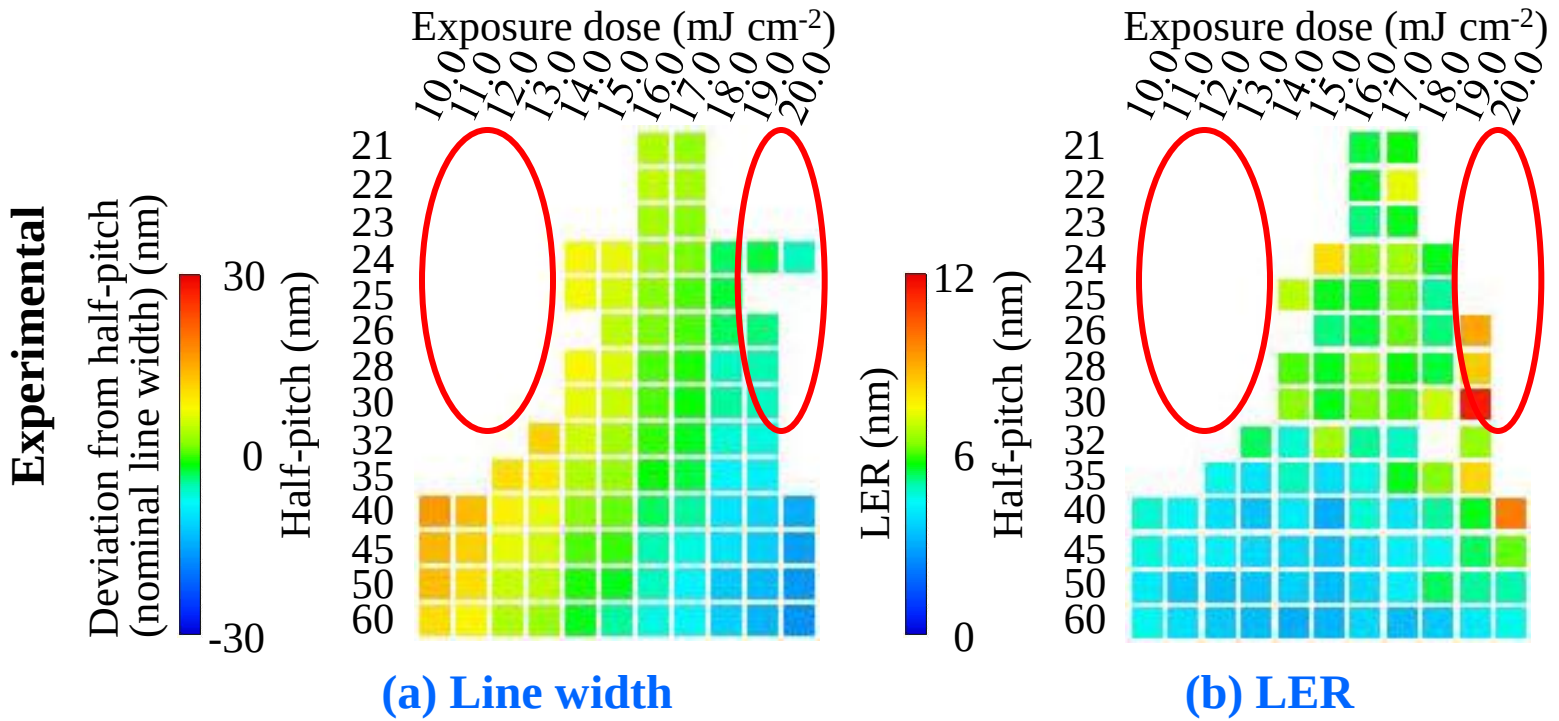
Dose-pitch matrices of EIDEC standard resist

Half-pitch dependence (16 mJ cm^{-2} exposure dose)



Exposure dose dependence (60 nm HP)





(a) Line width **(b) LER**

Analysis procedure

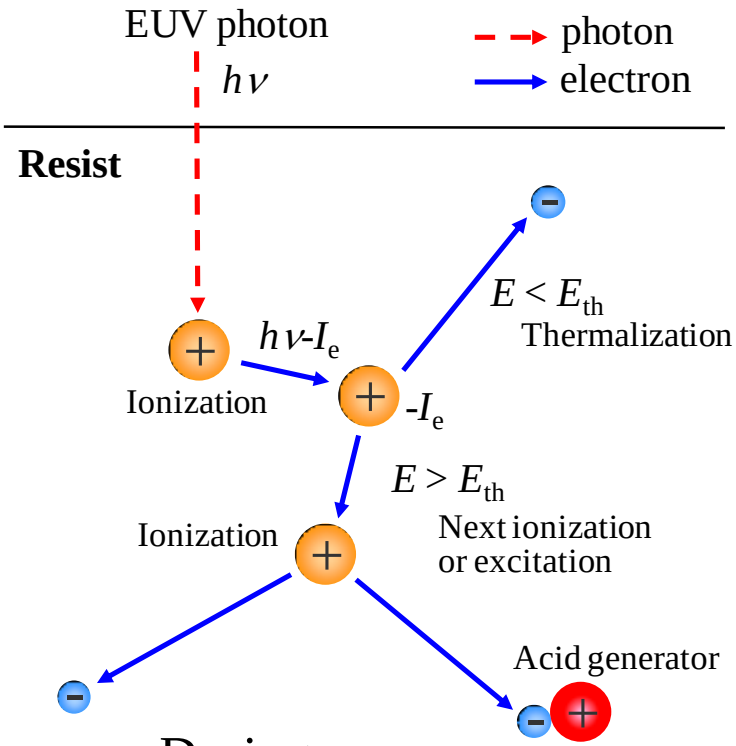
Stochastic effect was investigated using Monte Carlo method.
However, Monte Carlo method is not suitable for accurate calculation.

Acid generation | **Catalytic chain reaction**

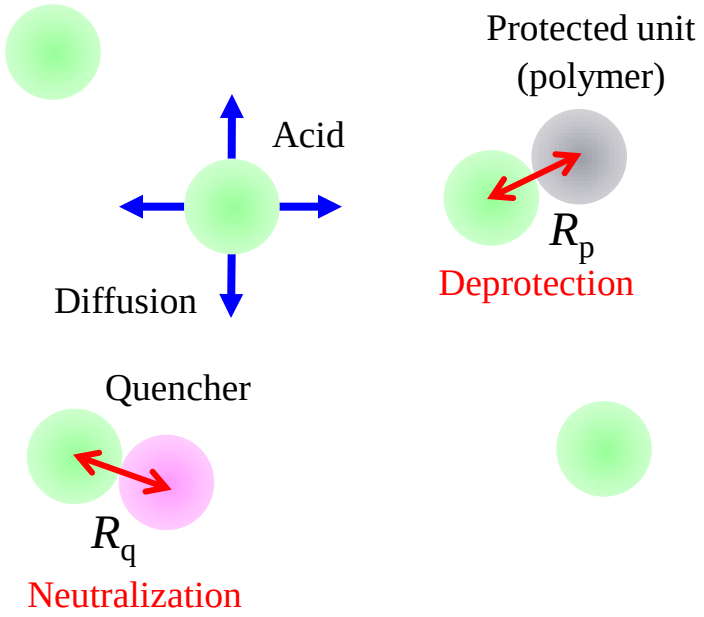
Step 1: Overall fitting – Probability density model
- Point spread function | Reaction diffusion equations

Step 2: Refitting with Monte Calro acid generation simulation – Hybrid model
- Monte Carlo method | Reaction diffusion equations

Step 3: Analysis with Monte Carlo process simulation – Stochastic model
- Monte Carlo method | Monte Carlo method



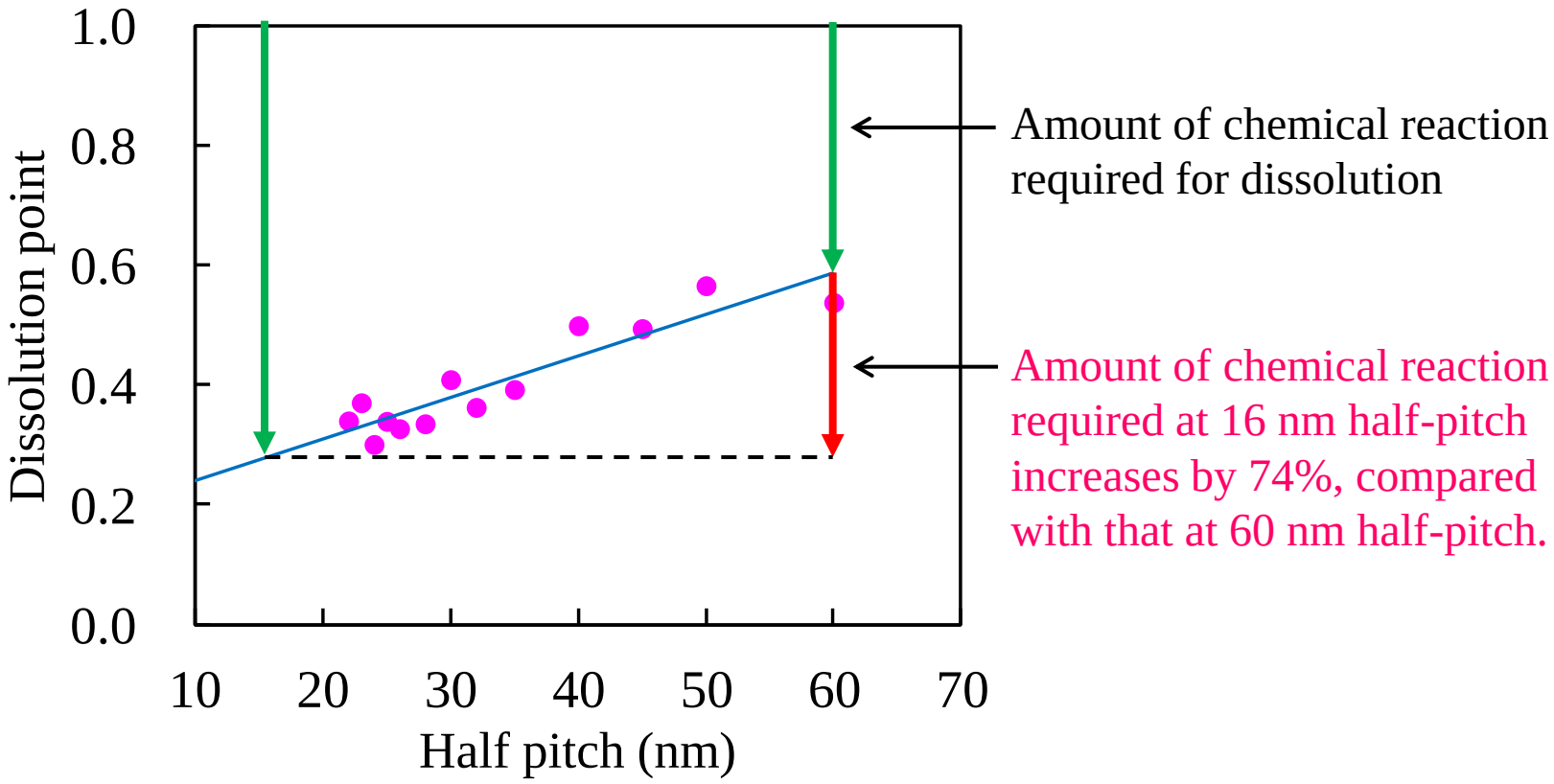
During exposure



During PEB

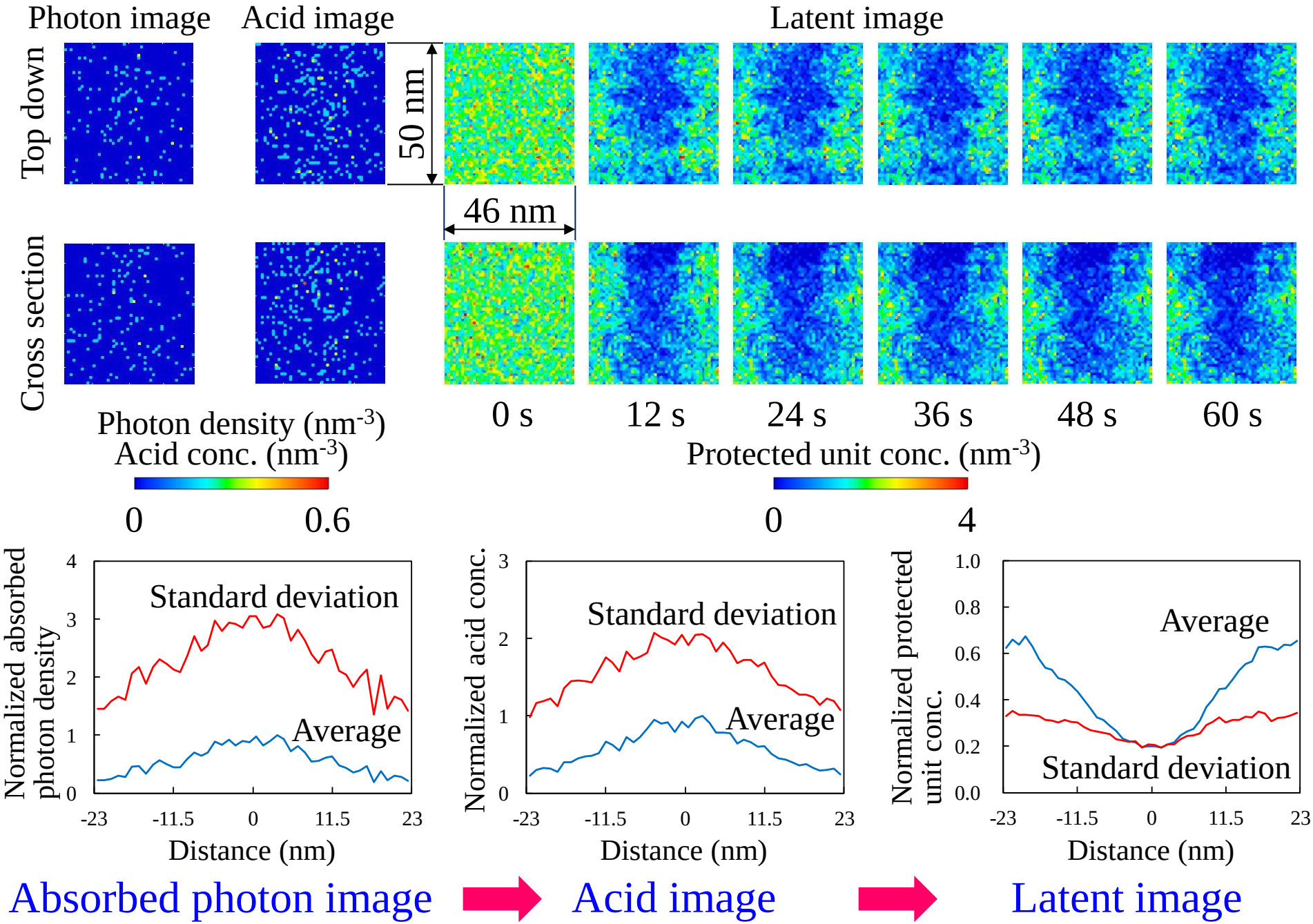
Best fit parameters

Effective reaction radius for deprotection: 0.16 nm
Effective quencher concentration: 0.023 nm^{-3}
Diffusion constant: 10 $nm^2\ s^{-1}$ (2~6 $nm^2\ s^{-1}$)
Proportionality constant between LER and chemical gradient f_{LER}: 0.22
Dissolution point:

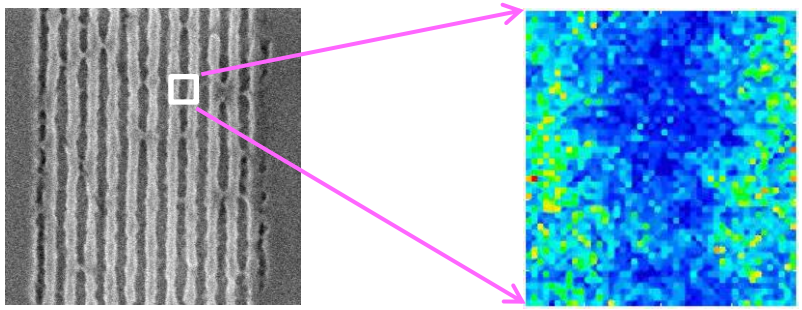


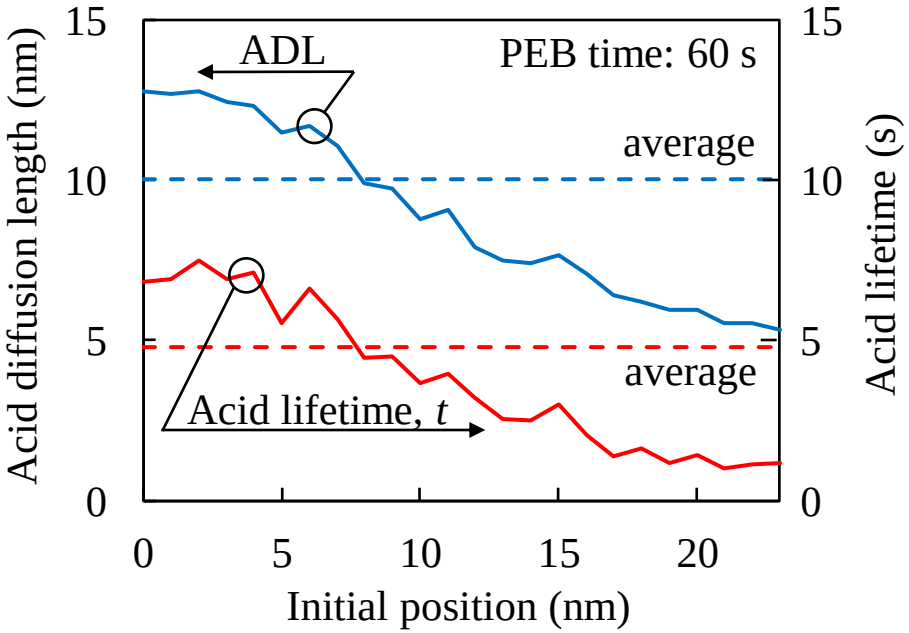
Dependence of dissolution characteristics on pattern size

Stochastic effect – 23 nm LS pattern at 16 mJ cm^{-2} exposure



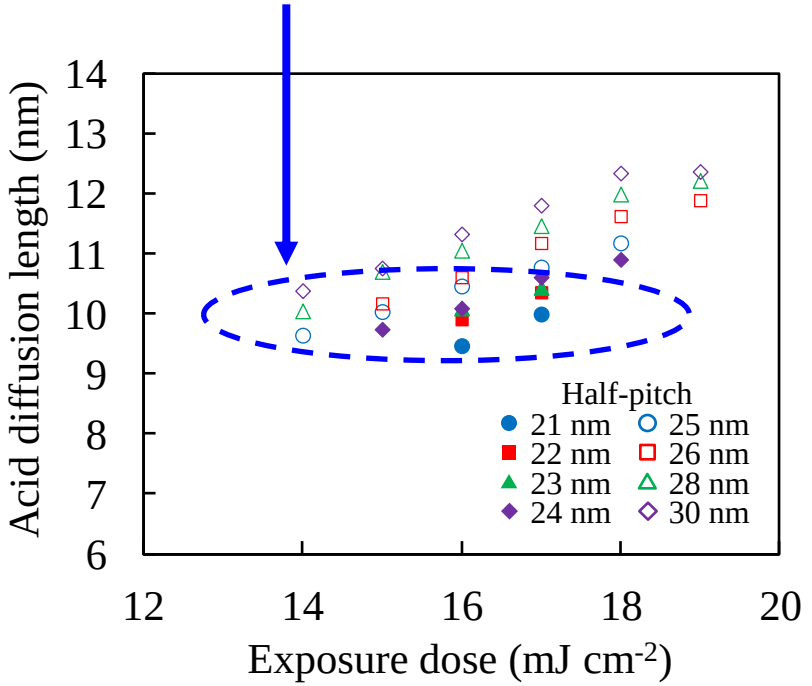
Acid diffusion length in EIDEC standard resist





Dependence of acid diffusion length and lifetime on the initial position of acids (23 nm HP, 16 mJ cm^{-2})

The polarity of resist polymer was sufficiently changed for the dissolution in developer with the acid diffusion length of 10 nm in the EIDEC standard resist.



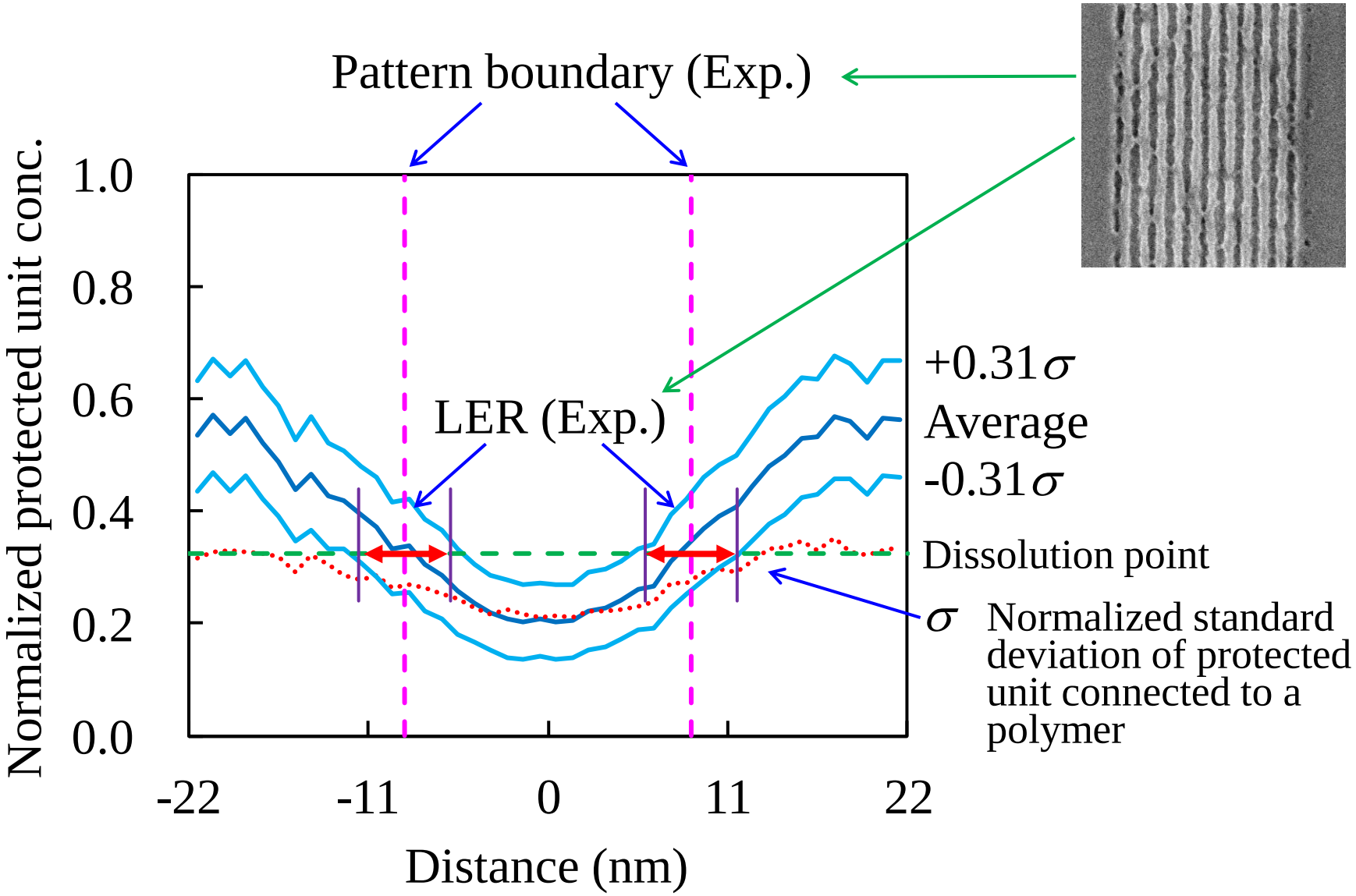
Dependence of acid diffusion length on half-pitch and exposure dose

The optimum acid diffusion length for 16 nm L&S patterns has been reported to be ~10 nm.

T. Kozawa, JJAP **52** (2013) 016501.

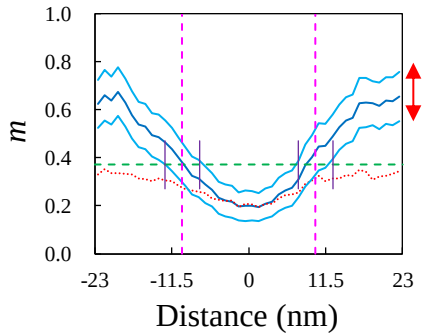
EIDEC standard resist has the potential for resolving 16 nm features with HQ EUV images.

Latent image of 22 nm LS pattern at 16 mJ cm^{-2} exposure



The fluctuation of protected unit concentration leads to the fluctuation of the crossing point between latent image and dissolution threshold.

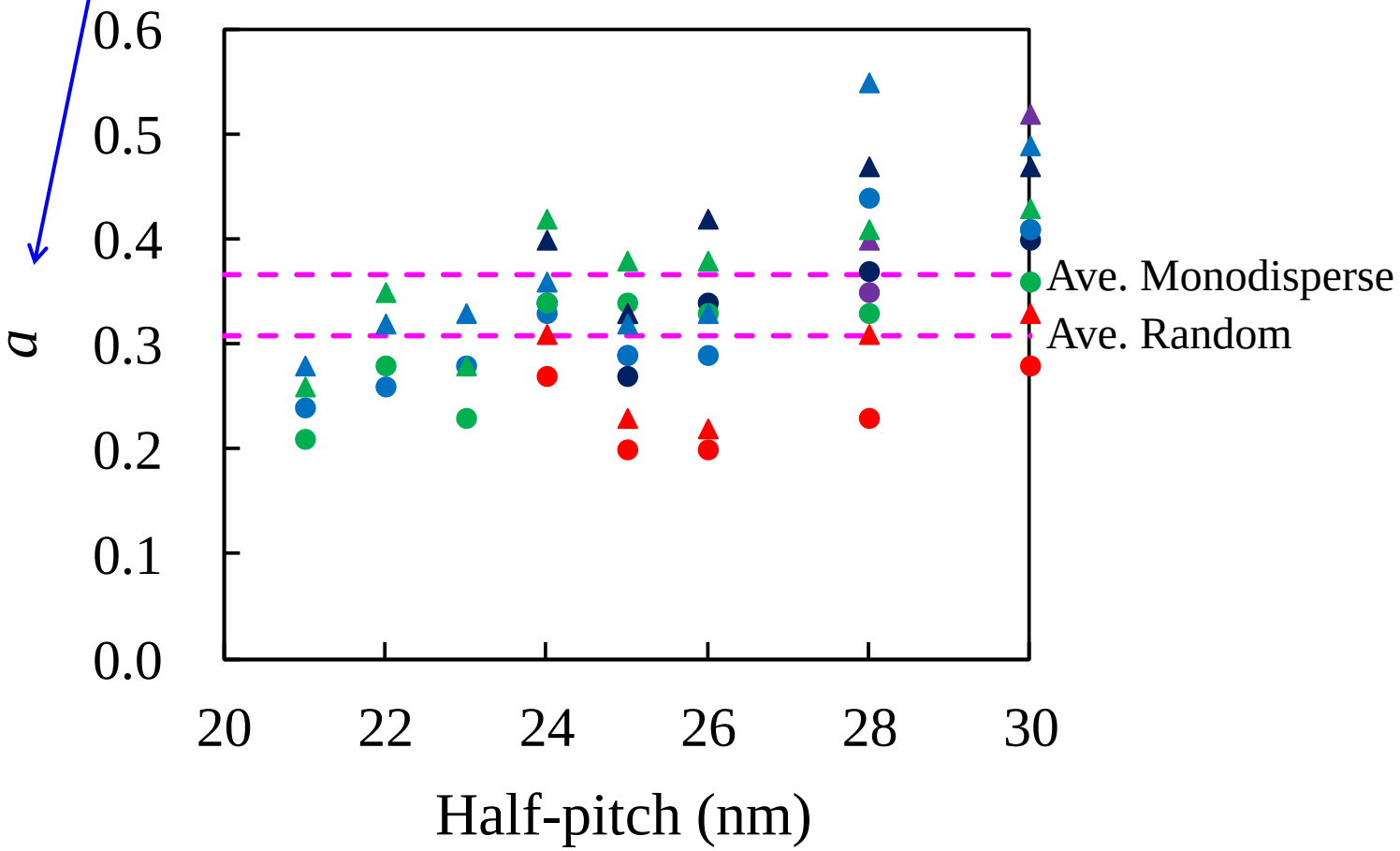
Relationship between protected unit fluctuation and LER



$\pm a\sigma$

▲ Monodisperse polymer
● Randomly protected polymer

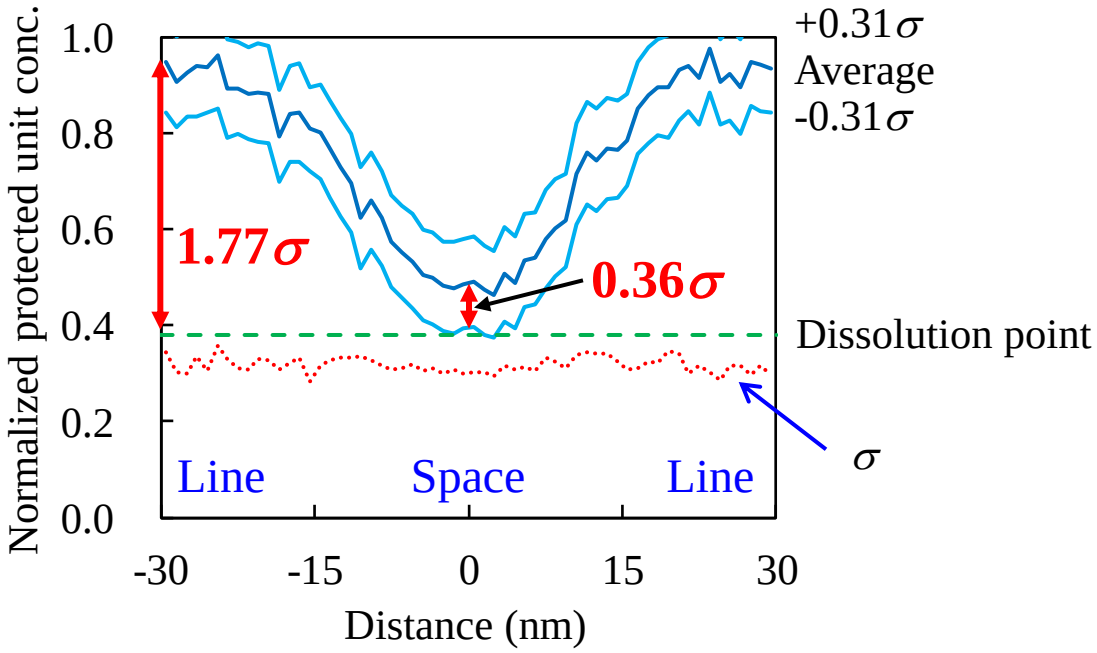
▲● 14 mJ cm^{-2}
▲● 15 mJ cm^{-2}
▲● 16 mJ cm^{-2}
▲● 17 mJ cm^{-2}
▲● 18 mJ cm^{-2}

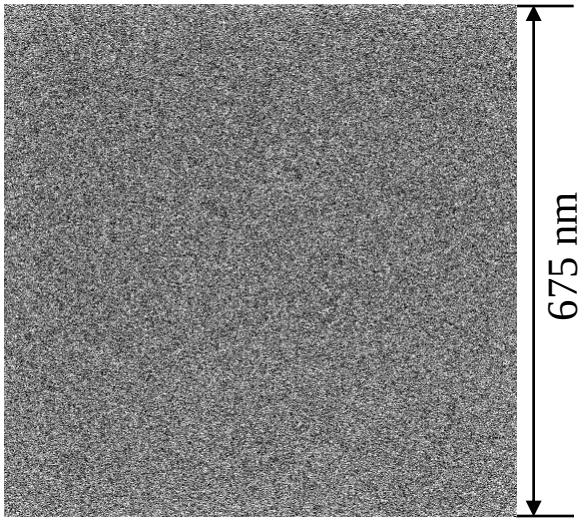


± 0.31-$\pm 0.37\sigma$ fluctuation of protected units contributes to LER formation.

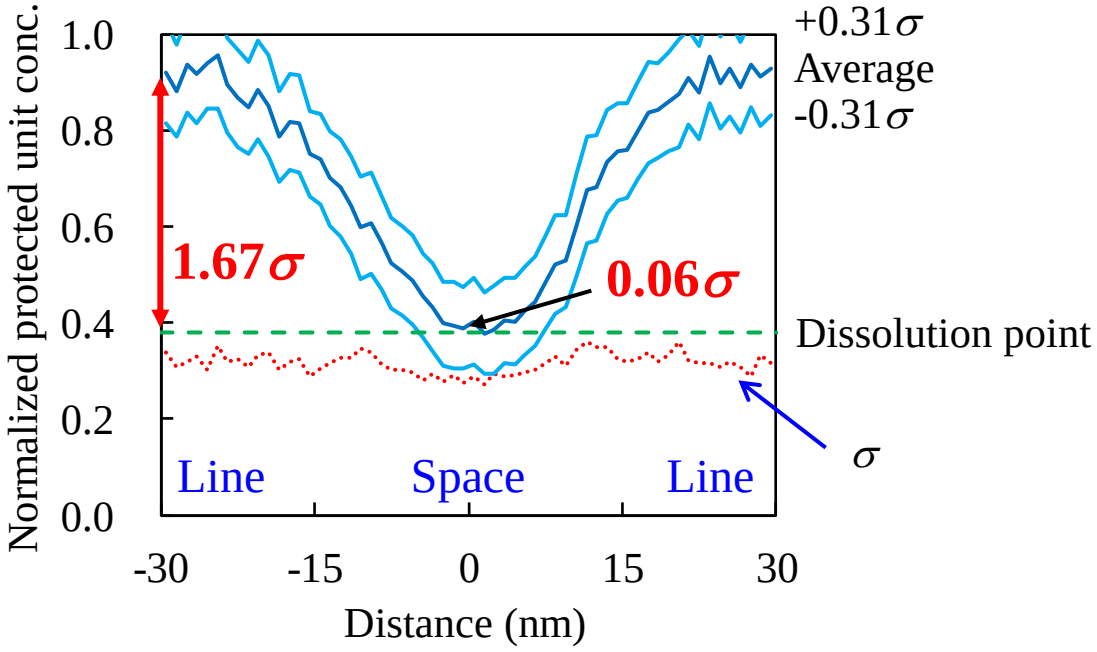
Relationship between latent and SEM images of 30 nm L&S patterns

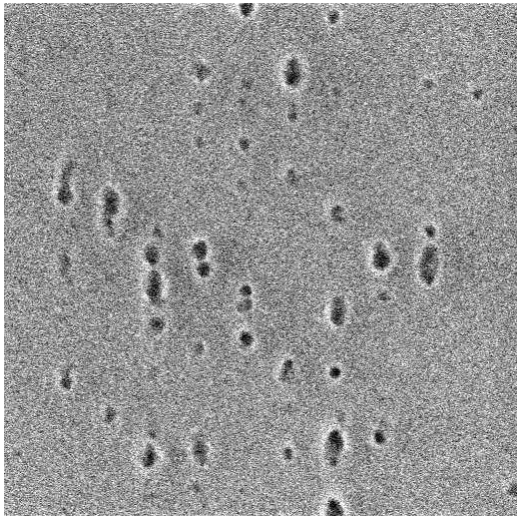
10 mJ cm^{-2}





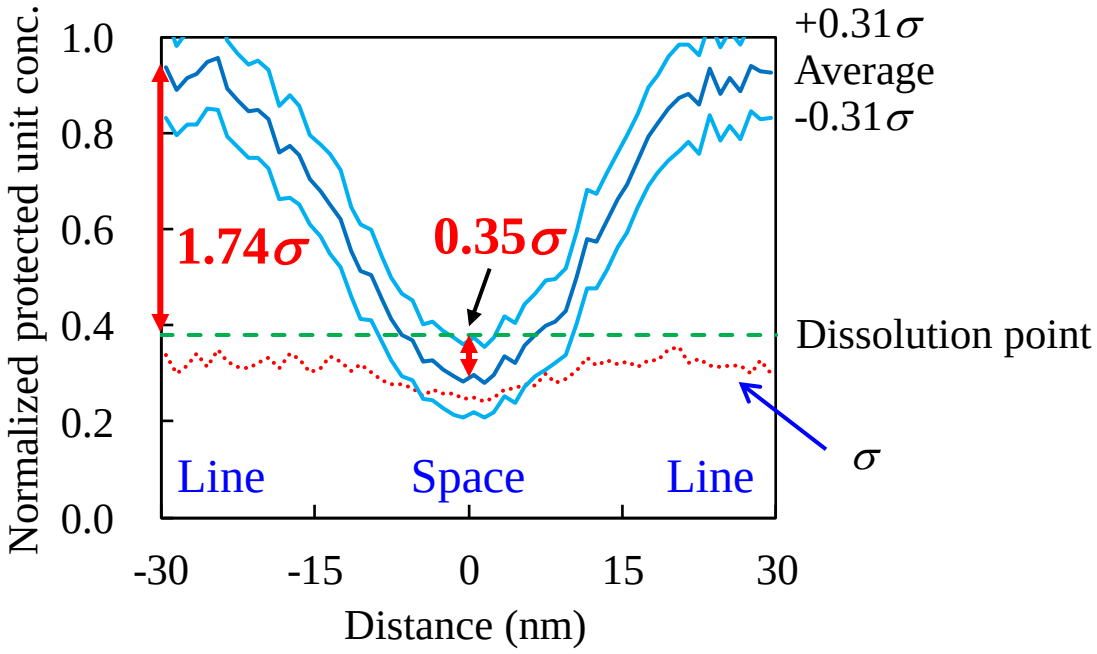
11 mJ cm^{-2}

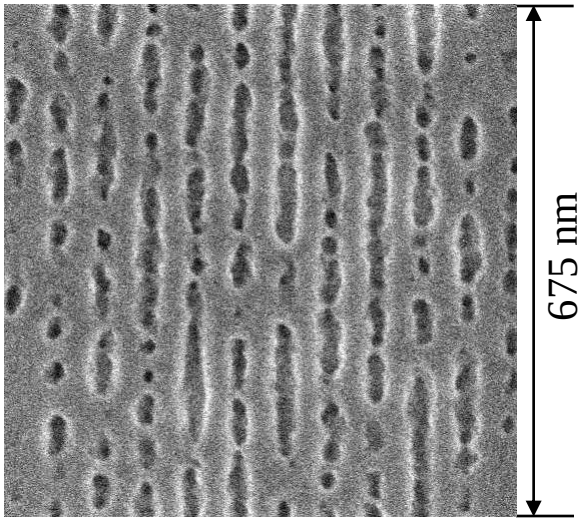




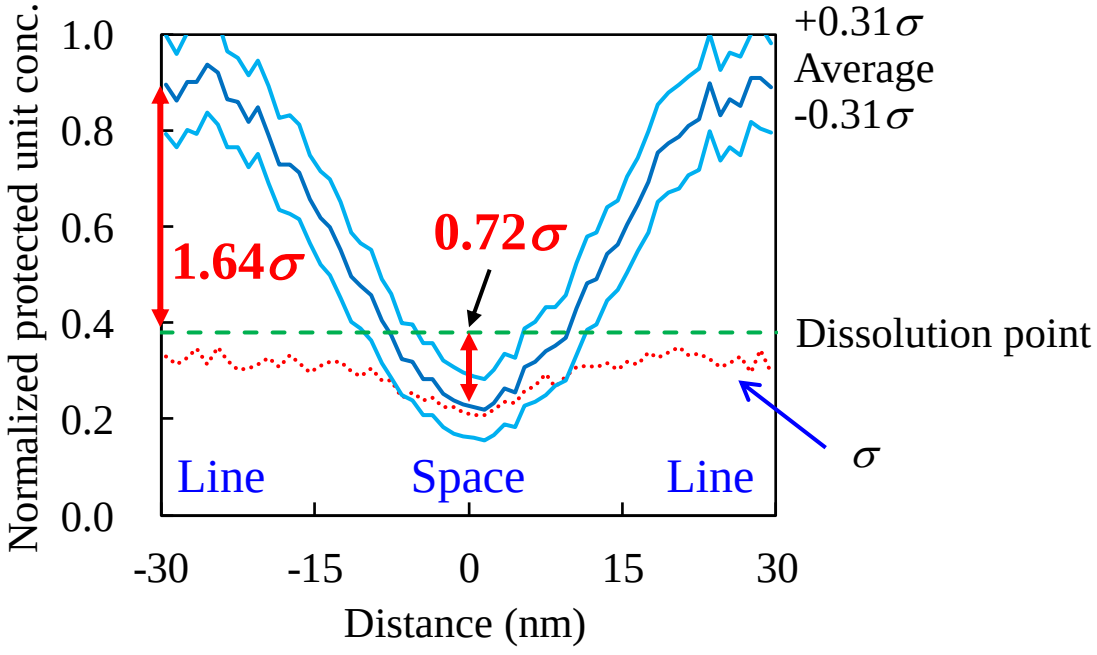
Relationship between latent and SEM images of 30 nm L&S patterns

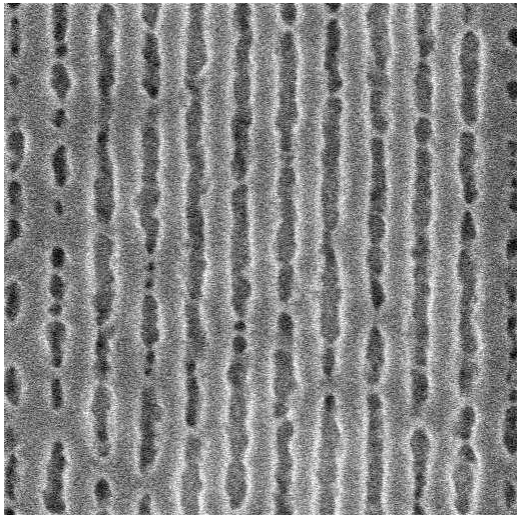
12 mJ cm^{-2}





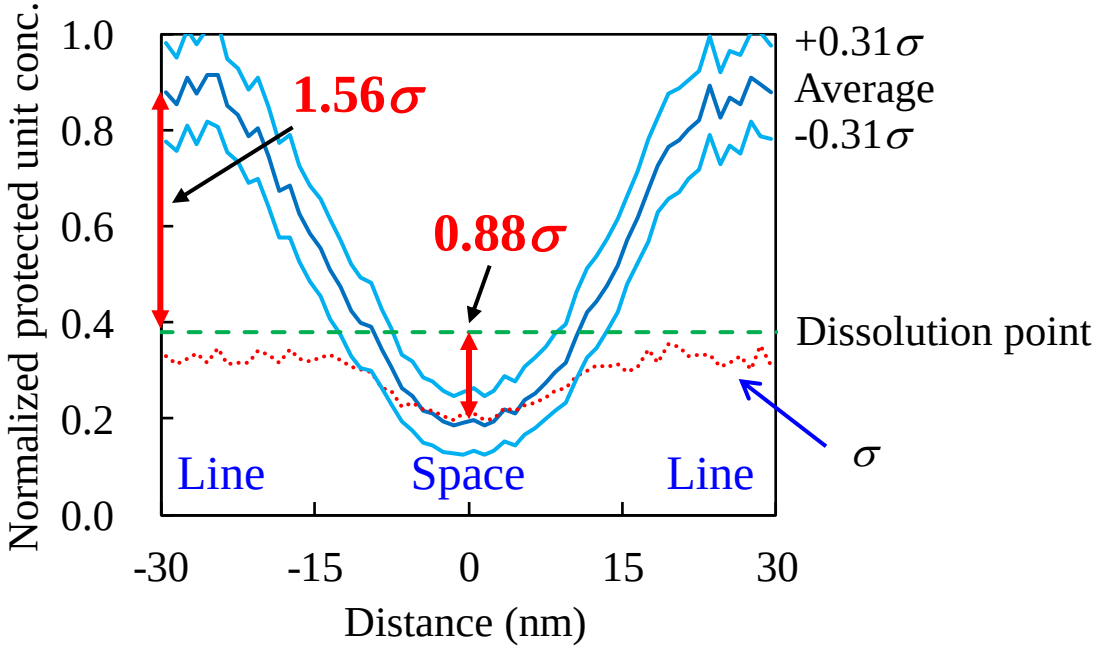
13 mJ cm^{-2}

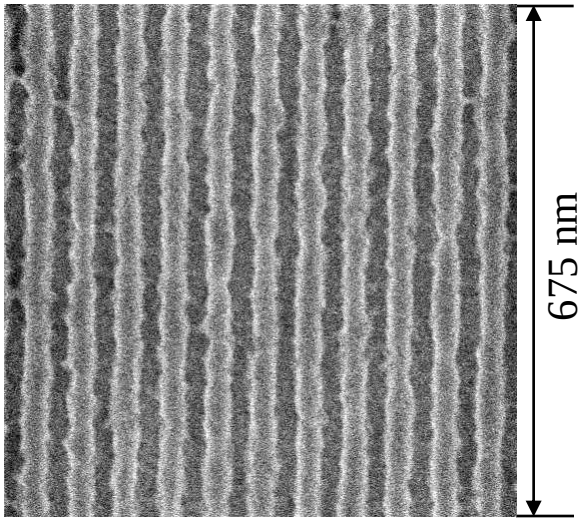




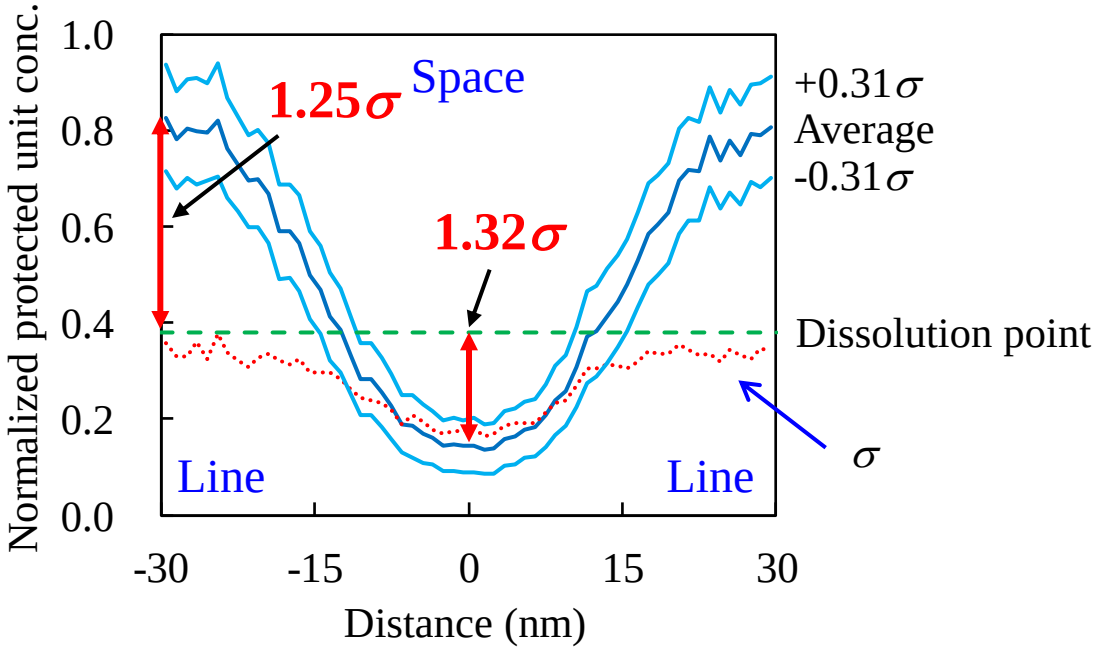
Relationship between latent and SEM images of 30 nm L&S patterns

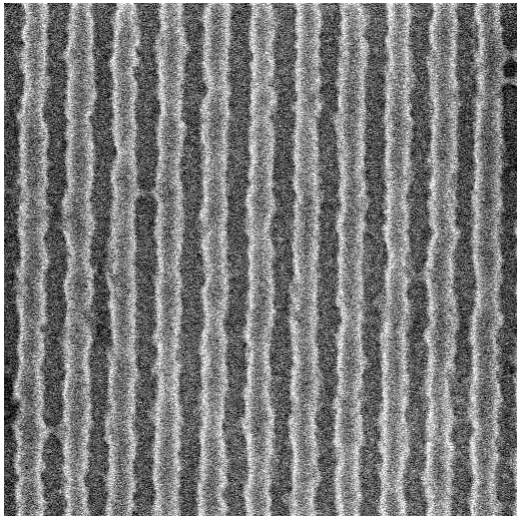
14 mJ cm^{-2}





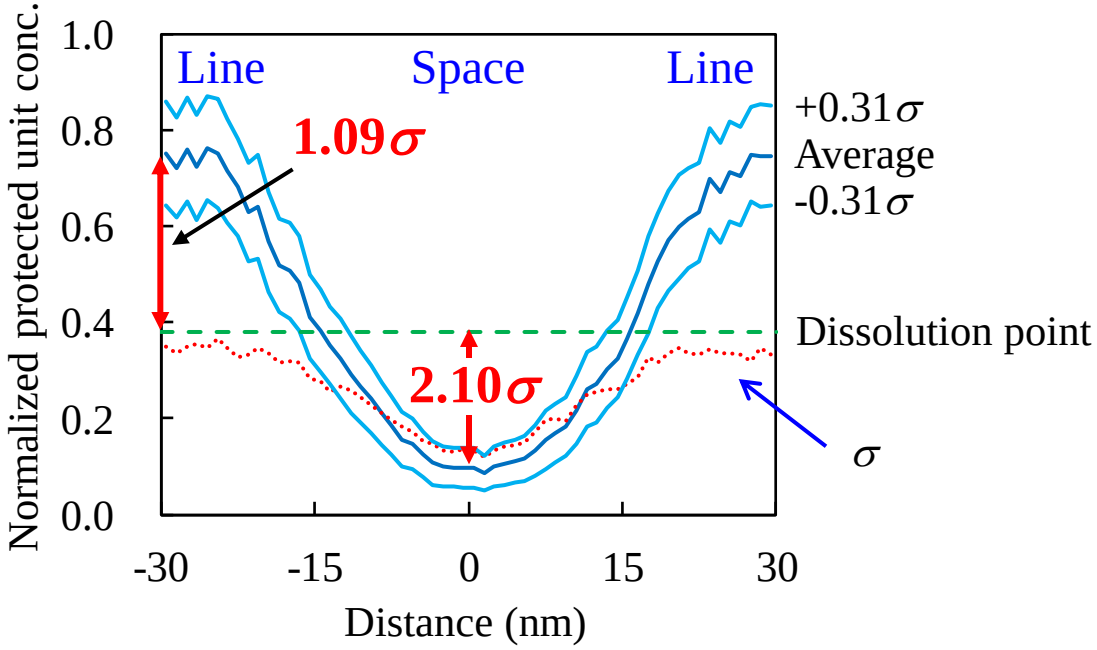
15 mJ cm^{-2}

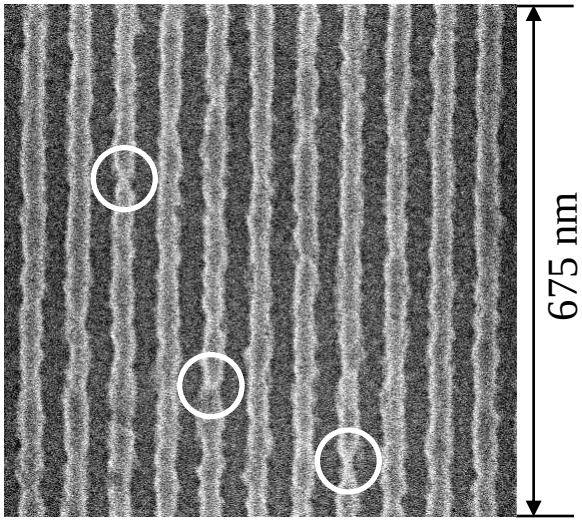




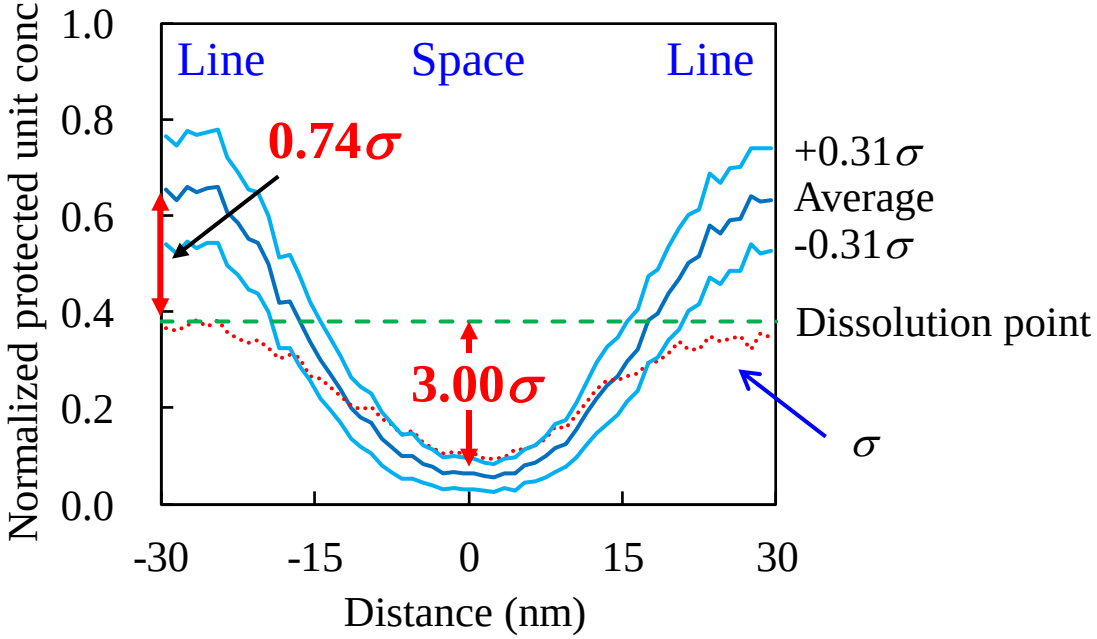
Relationship between latent and SEM images of 30 nm L&S patterns

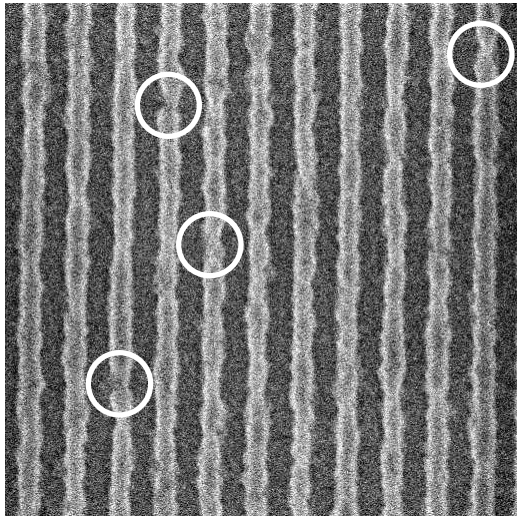
16 mJ cm^{-2}





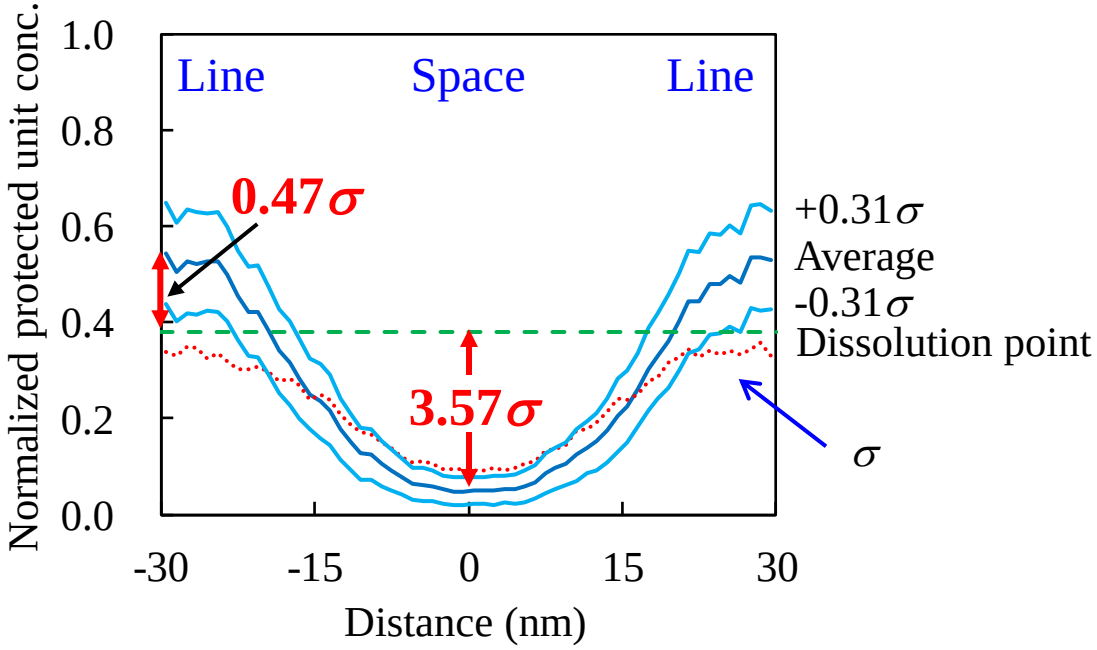
17 mJ cm^{-2}

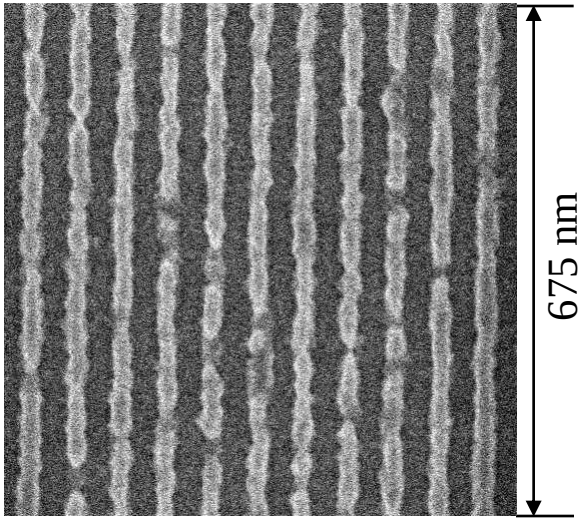




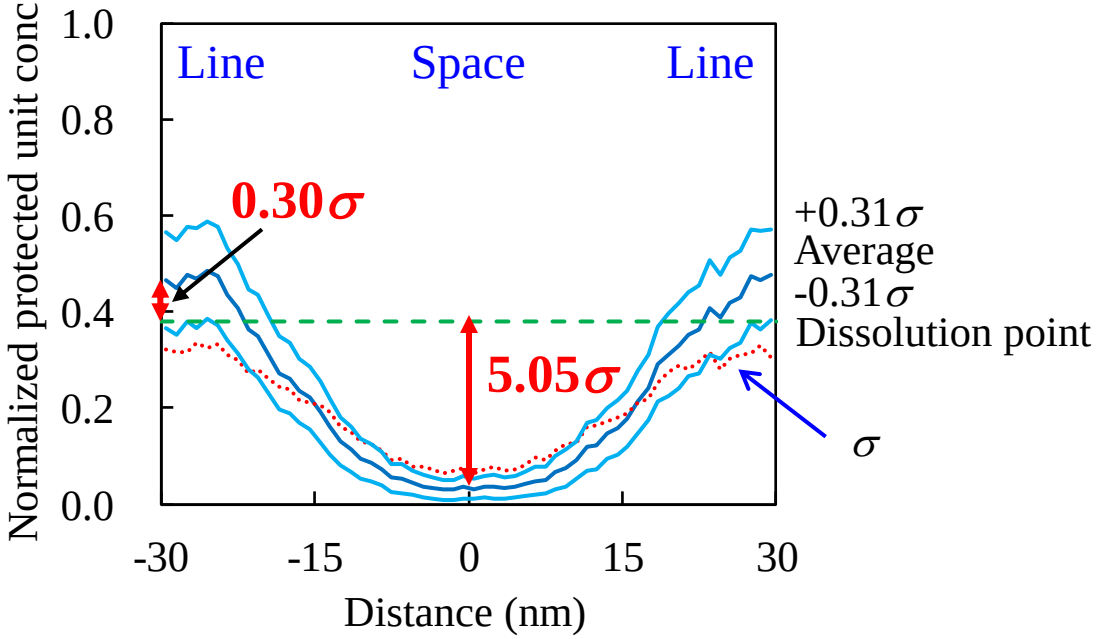
Relationship between latent and SEM images of 30 nm L&S patterns

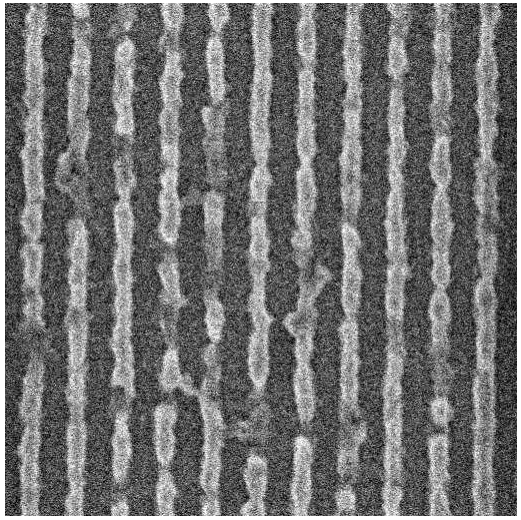
18 mJ cm^{-2}



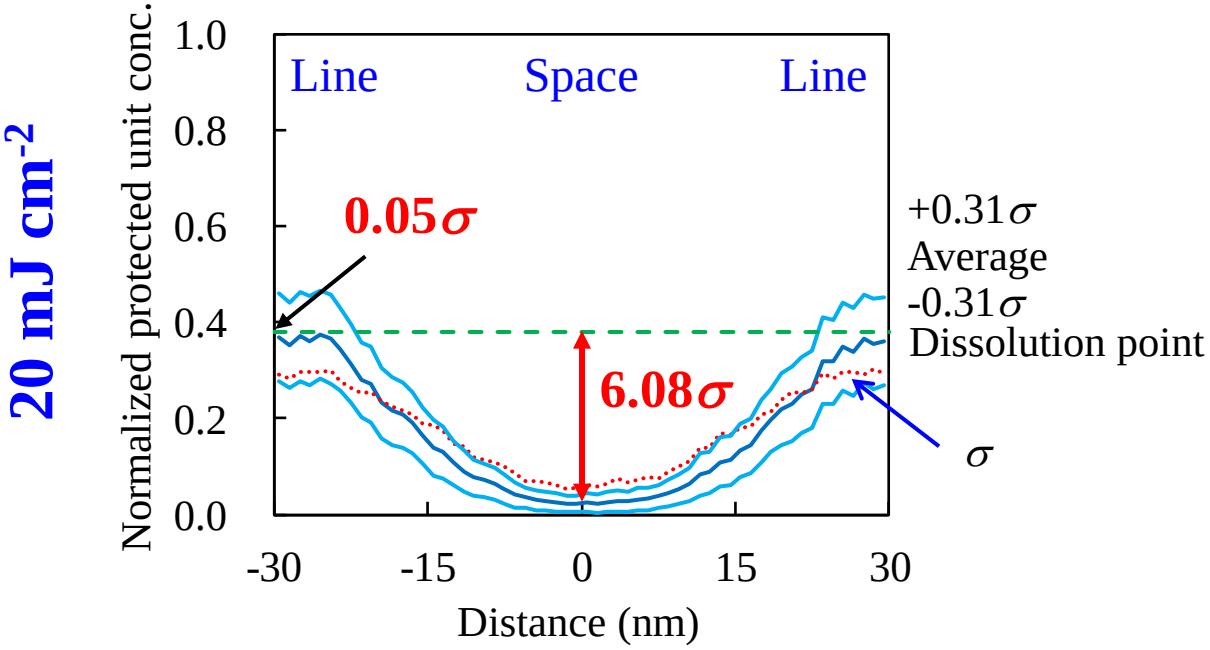


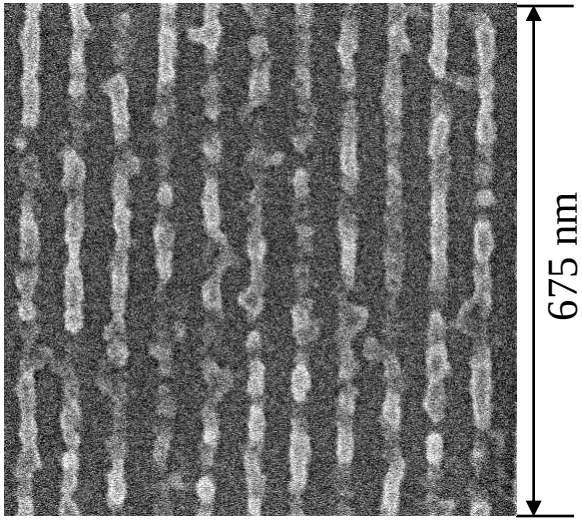
19 mJ cm^{-2}





Relationship between latent and SEM images of 30 nm L&S patterns

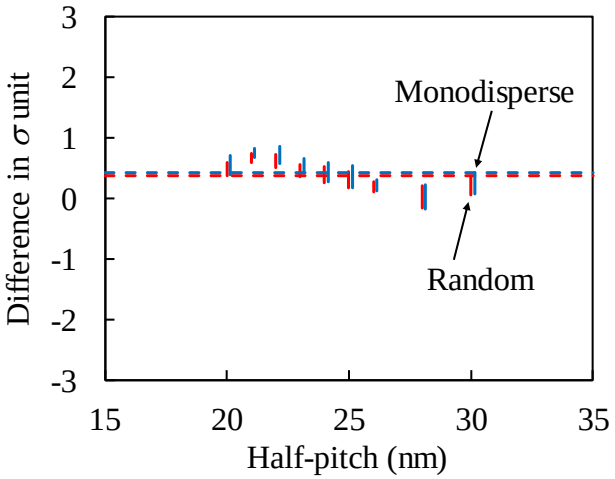




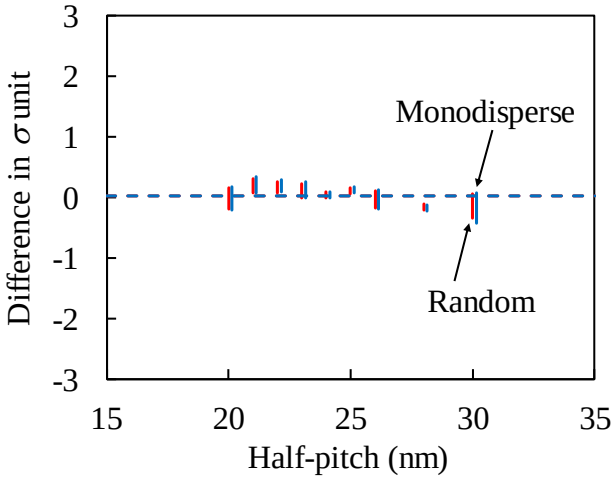
The same analysis was applied to the other SEM images.

Relationship between stochastic effect and resist pattern defects

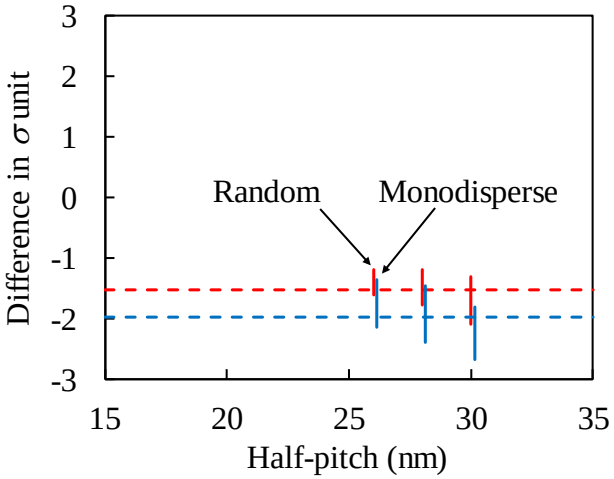
Space



Start of space appearance

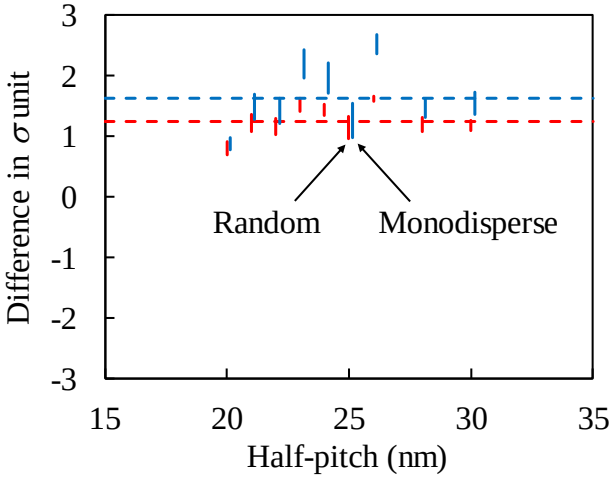


Half open

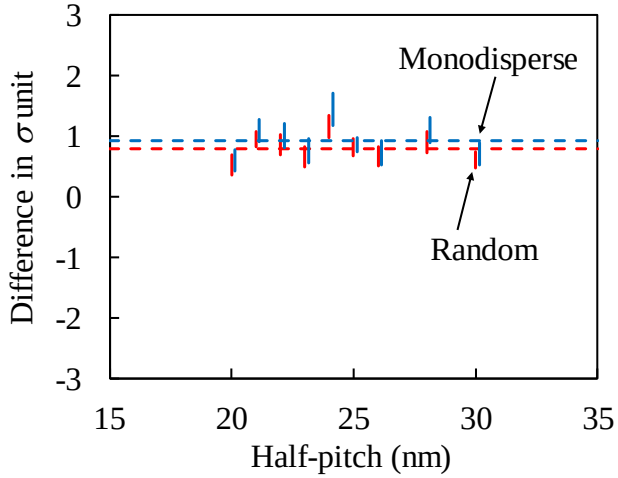


Elimination of bridge

Line



Appearance of severe line shrinkage



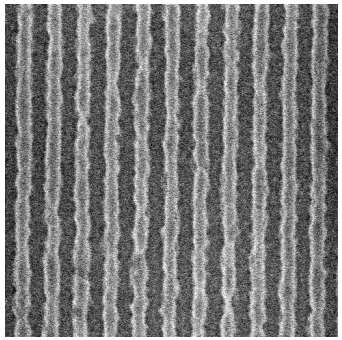
Appearance of line break

Definition of "Difference in σ unit"

$$(C_P\text{-}C_{DP})/\sigma$$

Difference between protected unit concentration and dissolution point

Summary – Advanced Resist Characterization



EIDEC Standard Resist

Latent image was successfully reconstructed from SEM image using a Monte Carlo simulation.

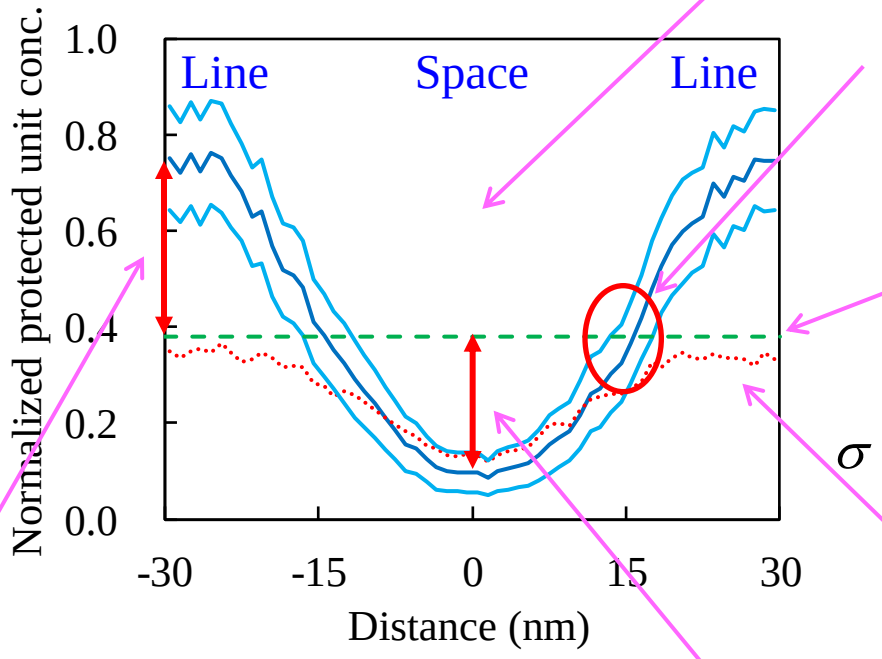
Chemical information was also obtained.

The acid diffusion length was approximately 10 nm in the high resolution region.

±0.31-±0.37 σ fluctuation of protected units contributed to LER formation.

The resolution dependence of dissolution point was estimated.

The fluctuation of protected unit (stochastic effect) was estimated.



To eliminate line shrinkages within 6.1 μm length, 1.2-1.6σ difference is required.

To eliminate bridges within 6.8 μm length, 1.5-2.0σ difference is required.

Acknowledgement

This work was partially supported by the New Energy and Industrial Technology Development Organization (NEDO).